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An Experimental Study on Tensile Characteristic for CFRP Cable without Surface Treatments

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Abstract

CFRP (Carbon Fiber Reinforced Polymer) cable can be advantageously used to overcome the problem of corrosion encountered in conventional PS steel strands. Since CFRP cable presents weakness against lateral pressure and stress concentration, the application of the anchorage system adopted for conventional PS steel strand is likely to fail in providing reliable resistance because of premature failure. Therefore, appropriate anchorage device needs to be developed for the anchoring of CFRP cable. The typical types of anchoring device for CFRP cable are wedge-type, bond-type and grip-type anchorages. Most of anchors are bond-type to measure the tensile property of CFRP cables. Generally CFRP materials like reinforcements, tendons, and cables have surface treatments to improve bond strength as sand coating, deformed shapes, fabricated covers and so on. In case of CFRP cable without surface treatment, its bond strength is much lower than CFRP cable with surface treatments. Accordingly, bond-type anchor may be long and tensile property of CFRP cable may be misestimated. In this study, tests for tensile property of CFRP cable without surface treatment have been performed. To improve the bond strength of CFRP cable, the end of the cable was split in order to widen bond area. The test results revealed that widening the end of CFRP improved the anchoring performance up to the ultimate strength of CFRP.

Selection

Keyworks: Carbon Fiber Reinforced Polymer, cable, anchor, tensile property, bond strength

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1. Introduction

Recently, CFRP (Carbon Fiber Reinforced Polymer) has recognized growing interest as an alternative material to replace steel reinforcement and steel wires owing to its non-corrosiveness, high strength and lightweight properties. Since CFRP exhibits weakness to lateral shear, a special anchoring device is required to measure its tensile properties. Currently, numerous anchorages and specifications have been suggested by ASTM(2008), ACI(2004), and CSA(2002) to measure the tensile characteristics of FRP. Two types of anchorages that are the bond-type and the grip-type anchorages are proposed in the specifications. The grip-type anchor is subjected to stress concentration in the grip similarly to the wedge-type anchor that makes it appropriate for low strength FRP and may necessitate a grip according to the diameter of the cable. Despite of the bond-type anchor requires sufficient anchorage length, this anchor is appropriate for high strength FRP which makes it the most widely used type for the tensile characteristics tests. The length of the bond-type anchorage varies according to the bond strength between FRP and the filler. The bond strength depends itself on the surface treatment, surface roughness and fabrication method of FRP. In the case of high strength FRP or in the case where the surface treatment has low strength or when there is no surface treatment, securing the tensile characteristics of the material becomes difficult if the length of the bond-type anchor is not sufficient.

This study intends to evaluate the tensile properties of the CFRP cable without surface treatment. To that goal, comparison of the tensile properties is done for bond-type anchorages with identical length with and without surface treatment. The extremity of the CFRP cable is varied to increase the bonded surface between CFRP and the filler and improve the tensile properties. Finally, the tensile characteristics are verified by applying a CFRP cable exhibiting small diameter and not subjected to surface treatment.

2. Preliminary test

2.1. Test Planning and Variables

This study conducted a preliminary test in order to verify the applicability of the bond-type anchor for the evaluation of the tensile properties of a CFRP cable exhibiting low strength and poor bonding characteristics. The bond-type anchor was fabricated with diameter of 42.7 mm and length of 400 mm (CSA, 2002). The diameter of the CFRP cable used for the test was 7.8mm, and two cases were considered according to the state of its surface. The first case corresponded to the cable with wrapping and sand coating, and the second case considered the cable without surface treatment as shown in Fig. 1. Five specimens were fabricated for each of the CFRP cables and inserted in the bond-type anchor. A UTM with capacity of 1000kN was adopted to perform the tensile test.

2.2. Test Results

All the cables failed through debonding at the interface between the CFRP cable and filler. Slip occurred also in the wrapped and sand coated case despite of the surface treatment. This can be explained by the fact that sand coating and wrapping were applied after the fabrication of the CFRP cable, which generated an interface where debonding could occur between the surface treatment and the cable itself. For the cable without surface treatment, slip occurred under low tensile strength because of the small frictional force between the CFRP cable and filler. Accordingly, an adequate method increasing the bond strength should be applied in order to evaluate the tensile properties of a CFRP cable with low surface bond strength like when the surface treatment process is executed after the fabrication of the CFRP cable and when the cable is not subjected to surface treatment.

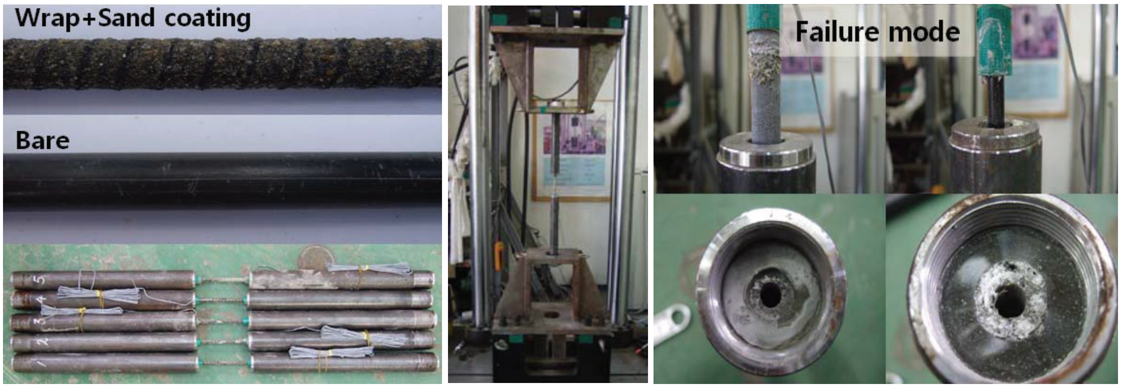
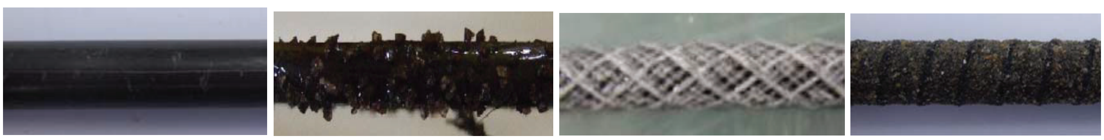


Figure 1: Preliminary test.

2.3. Improvement of Bond Performance

An anchorage method enabling to increase the bond performance is required to determine the tensile properties of the CFRP cable with low bond strength. In general, this can be achieved by increasing the length of the anchor or by increasing the frictional force through the application of surface treatment like sand coating on the surface of CFRP. In addition, the bond strength can also be increased by fabricating the core and the cover at once during the manufacture of FRP (Fig. 2). Even if various methods improving the frictional force by diverse surface treatments on the FRP are applied, these also present the disadvantage of requiring longer bond length in the case where the bond performance is not improved.

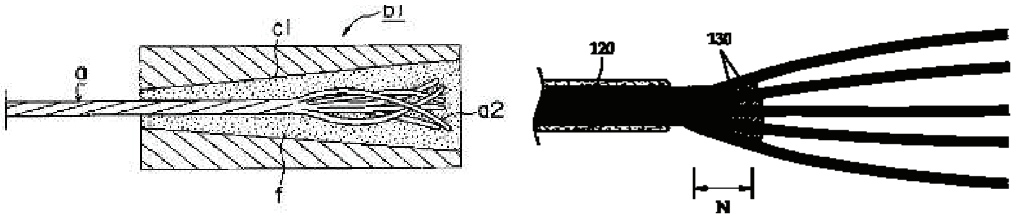


(a) No treatment (b) Oxide coating (c) X-type fabricated (d) Wrap+sand coating

Figure 2: Various surface treatments.

A method to realize the anchorage with a small length is to spread the end of the PS strand (12.7 mm) at its end so as to anchor 7 wires. In such case, the bond surface is increased by about 2.3 times compared to the original shape (Fig. 3(a)). The PS strand can be spread into wires but this cannot be easily done for the fibers of FRP since the fiber are bound by resin. Need is thus for a method removing the resin at the end of FRP. This is commonly achieved by chemical decomposition and thermal decomposition. However, this method requires to remake the end using the resin after the removal of the resin, which implies to spend a long time for the fabrication. Especially, the determination of the tensile properties of FRP becomes difficult because of the possibilities of the breakage of the part connecting the original section and the remodeled section due to damages of the fibers and stress concentration.

Apart from the chemical decomposition and thermal decomposition for the complete removal of the resin, another method enabling to widen the bond surface by spreading the end of the CFRP cable is to divide the resin in the direction of the fibers. Generally, the fibers of CFRP reinforcement, tendon and cable are produced unidirectionally and the resin plays the role of binder. If the resin is divided regularly at the end of the CFRP cable, the resin can be easily split in the direction of the fibers (Fig. 3(b)). Such method provides smaller bond surface than the conventional method removing completely the resin but offers good workability and does not require to remake the end since it applies new resin. This study applies this method to evaluate the tensile properties of the CFRP cable with low bond performance.



(a) PS steel strand(東京製綱株式會社, 1998) (b) CFRP(KICT, 2010)

Figure 3: End shape for improving anchor performance(Patent applications).

3. Tensile Properties Test of CFRP Cable

3.1. Test Planning and Variables

This study conducted the tensile test by widening the bond surface at the end of the CFRP cable under conditions identical to those of the preliminary test. The end of the CFRP cable was divided into 4 equal parts to increase the bond surface by dividing the resin in the direction of the fibers as shown in Fig. 4. The bond surface of the CFRP cable used in the preliminary test reached approximately 9,800 mm^2 whereas the widened bond surface increased by about 2.2 times to reach 22,000 mm^2. Moreover, the frictional force was expected to increase following the application of a wedge inside the bond-type anchor since the end of the CFRP cable was widened.

(a) Specimen-making (b) Failure mode

Figure 4: Tensile test on modified bond type anchor.

3.2. Test Results

The failure of the specimen with wrapping and sand coating occurred through the rupture of CFRP and slip as shown in Fig. 4. The specimen without surface treatment failed through slip induced by debonding. Table 1 arranges the tensile strengths for the case with increased bond surface at the end and the case without increase. Compared to the preliminary test, the widening of the bond surface at the end resulted in the improvement of the tensile performance by 54% for the surface treated cable and by about 190% for the non-treated cable.

Table 1: Tensile test results of CFRP cable

	With surface treatment (wrap+sand), MPa	*Without surface treatment, MPa*
Preliminary test (common bond-type anchor)	1904	349
The present study (modified bond-type anchor)	2933	1022

The results showed that the increase of the bond surface had significant effect in the tensile and anchoring properties in the case of the cable without surface treatment. In addition, it appeared also that debonding remained the cause of failure. Such debonding failure occurred by splitting in the direction of the fibers caused by the concentration of stress in the divided fibers and unbalanced anchor force following the reduction of the cross-sectional area due to damages in the fibers when the resin was divided at the end of the cable.

In order to prevent such the slip failure, the spread part and the non-widened part were reinforced by wrapping with CFRP sheet. The effect of the sheet reinforcement was verified by a test using a CFRP cable with diameter of 5 mm and without surface treatment.

The test results showed that the failure mode occurred through rupture of CFRP as shown in Fig. 5 and that the CFRP cable developed its maximum tensile strength. Accordingly, increasing the sectional area of the end of the cable is necessary to evaluate the tensile performance of the CFRP cable with low bond strength. Complementarily, it is also recommended to reinforce the part where widening starts to prevent debonding in the direction of the fibers so as to evaluate properly the tensile properties of the CFRP cable.

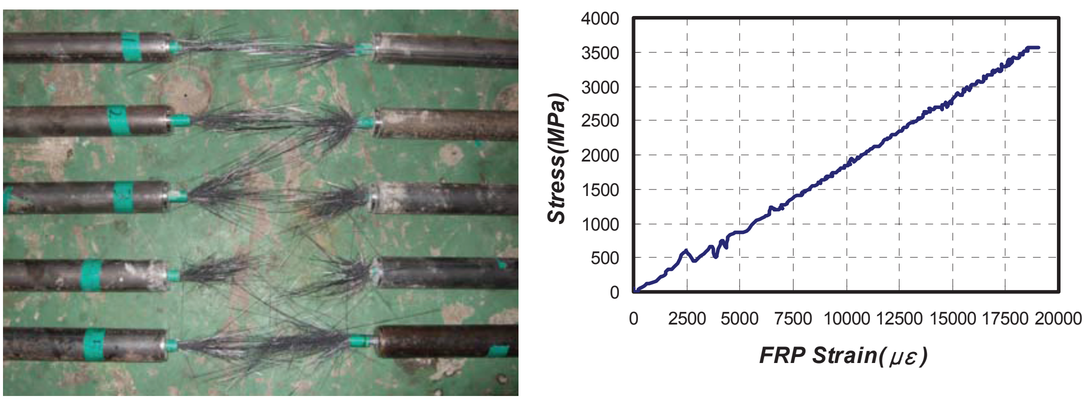


Figure 5: Failure mode of specimens with modified bond anchor.

4. Conclusions

Tensile tests were performed using the bond-type anchor in order to evaluate the tensile properties of CFRP cables without surface treatment. The importance of the anchor performance of the end of the CFRP cable appeared to be of critical importance in the evaluation of the tensile characteristics. Especially, a method increasing the bond surface of the end of the cable was required since the cable without surface treatment exhibits low bond strength. In order to increase the bond surface, this study widened the end of the CFRP cable by dividing regularly the end section and splitting the resin in the direction of the fibers. In addition, the end was also reinforced by CFRP sheet to prevent slip in the direction of the fibers caused by the unbalanced anchor force. As a result, the tensile properties of the CFRP cable could be evaluated.

Acknowledgments

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